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MINERAL COMMODITY REPORT

—— SULFUR ——

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1984

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

SPECIAL PUBLICATION 74

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MINERAL COMMODITY REPORT

—— SULFUR ——

1984

By
Melvin C. Stinson

Part I adapted from
the U.S. Bureau of Mines publication,
Mineral Commodity Summaries, 1984

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY
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INTRODUCTION

This report on the availability and demand for sulfur in California, the United States, and the world is one of a series of Mineral Commodity Reports prepared by the California Department of Conservation, Division of Mines and Geology (DMG) to describe commodities of significance to California and the nation.

This mineral commodity report was compiled by Gary Taylor of the DMG geologic staff. Part I consists of United States and world-wide mineral-statistic information and economic analysis adopted directly from the U.S. Bureau of Mines "Mineral Commodity Summaries, 1984." Part II discusses production of the commodity in California. The U.S. Bureau of Mines presents the earliest Government estimates of non-fuel mineral-industry data, including world resource data provided by the U.S. Geological Survey.

Sulfur is nonmetallic element that is found in nature in both the native (elemental) state and in combination with other elements. Sulfur has many and varied uses. Its principal use is for the production of sulfuric acid, an acid that is used so extensively by modern industry that it is considered an index of a nation's economic activity. The largest sulfuric acid consuming industry in the United States is the fertilizer industry. Other uses of sulfuric acid include the manufacture of chemicals, paints, pigments, rayon, film, coal products, industrial explosives, petroleum refining, iron and steel pickling, and textile processing. The principal non-acid uses of sulfur are fertilizers and insecticides, the manufacturer of pulp and paper, explosives, dyes, rubber, and the preparation of food products.

Nearly all of the native sulfur deposits in California are associated with volcanic rocks. Production has been from Alpine, Colusa, Imperial, Inyo, Kern, Lake, and Shasta counties. The most productive counties have been Alpine and Inyo counties. Native sulfur has not been recovered from native sulfur ores since the 1960s. All sulfur produced in California in recent years has been from the treatment of sour or sulfurous crude oils and gases, and waste-acid sludges from petroleum refiners. In years past, sulfur was recovered in California from pyrite (iron sulfide) and smelter gases.

California with its diversified agricultural and industrial enterprises will continue to consume large amounts of sulfur obtained from imports into the state and as a by-product from petroleum refineries in the San Francisco Bay area and the Los Angeles area. Total production of by-product sulfur in California in 1982 was approximately 500,000 metric tons with a value of about $33 million.

For further information, please call (916) 445-5716, the DMG centralized information number.

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PART I: UNITED STATES AND WORLDWIDE

1. UNITED STATES PRODUCTION AND USE

In 1983, sulfur was produced at 194 operations in 32 states, Puerto Rico, and the Virgin Islands for a total shipment value of $950 million. Texas and Louisiana accounted for 53% of production. Ten companies with 65 operations accounted for 71% of production. Frasch sulfur was produced in Texas and Louisiana by four companies operating seven mines, with the five largest mines accounting for 31% of domestic production in all forms. Recovered elemental sulfur was produced as a coproduct at petroleum refineries, natural gas operations, a coking plant, and coal burning powerplants in 27 states, Puerto Rico, and the Virgin Islands by 56 companies with 155 individual plants. Sulfur was also produced in the form of sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide in 17 states by 14 companies with 32 operations. Sulfur shipped for domestic consumption was obtained mainly from domestic sources: recovered, 41%; Frasch, 32%; and combined coproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 10%. The remaining 17% of the sulfur was obtained by imports of Frasch and recovered sulfur. About 85% of the sulfur was converted to sulfuric acid prior to end use. Agricultural chemicals (fertilizers) accounted for 65% of sulfur demand. Organic chemicals, inorganic chemicals, and other chemical products accounted for 9%, petroleum refining 9%, and metal mining 5% of the sulfur demand. Other uses, 12% were widespread, as most products produced by industry require sulfur in one form or another during some stage of their manufacture.

2. SALIENT STATISTICS--UNITED STATES

(Data in thousand metric tons, unless noted)

	1979	1980	1981	1982	1983e
Production: Frasch	6,357	6,390	6,348	4,210	3,100
Recovered elemental	4,070	4,073	4,259	4,404	4,800
Other forms	1,674	1,403	1,538	1,173	1,100
Total	12,101	11,866	12,145	9,787	9,000
Shipments: All Forms	13,289	12,918	11,655	9,115	9,850
Imports for consumption: Frasch and recovered	2,494	2,523	2,522	1,905	1,750
Exports: Frasch and recovered	2,044	1,782	1,392	961	950
Apparent consumption: All forms[1]	13,739	13,659	12,785	10,059	10,650
Price (reported): Average value per ton of elemental sulfur f.o.b. mine/plant	$55.75	$89.06	$111.48	$108.27	$98.00
Stocks, Producer, yearend	4,239	3,094	3,634	4,202	3,350
Employment[e]: Mine/plant	4,000	4,000	4,000	3,700	3,800
Net import reliance[2] as a percent of apparant consumption	11	14	5	4	16

e Estimated.
1 Measured by shipments, plus imports, minus exports
2 Defined as imports - exports + adjustments for Government and industry stock changes.

3. RECYCLING

About 800,000 tons, sulfur content, of spent acid was reclaimed from petroleum refining and some chemical processes.

4. IMPORT SOURCES (1979-1982)

Canada 60.0%, Mexico 39.9%, Other 0.1%.

5. TARIFF

Item	Number	Most Favored Nation (MFN)		Non-MFN
		1/1/84	1/1/87	1/1/84
Sulfur (crude)	415.45	Free	Free	Free

6. DEPLETION ALLOWANCES

22% (Domestic), 22% (Foreign).

7. GOVERNMENT STOCKPILE

None.

8. EVENTS, TRENDS, AND ISSUES

World sulfur production declined for the third consecutive year. United States sulfur demand exceeded domestic production for the eighth consecutive year. Industrial demand for sulfur increased 2% and demand for sulfur in fertilizer manufacture increased 6% from that of 1982. World sulfur demand declined for the second consecutive year. Shipments of recovered elemental sulfur from petroleum refineries and sour gas processing plants exceeded Frasch sulfur shipments for the second time in 1983. Frasch sulfur mines were operating at about 50% of capacity for most of the year. One Frasch mine was closed at the end of November. For the seventh year, the United States showed a net import reliance. Tests being conducted on sulfur-asphalt paving and sulfur concretes will probably lead to increasing demand for sulfur in these uses. From a 1981 base, demand for sulfur is expected to increase at an annual rate of about 3.0% through 1990. It is estimated that in 1984 domestic production of sulfur will be 10.5 million tons and U.S. apparent consumption will be 11.8 million tons.

The average shipment value per ton of Frasch and elemental sulfur f.o.b. mine/plant increased about 9% from that of 1982. In April, the posted price for sulfur ex-terminal Tampa, Florida, was reduced to $130.41 per ton from $132.90 per ton. Price discounting from the posted price was widespread for the remainder of the year. Domestic spot prices fell $10 to $15 per ton in the first 10 months. International spot prices fell $20 to $30 during the same period.

Prices began firming in October and there was no further price deterioration during the remainder of the fourth quarter.

Domestic production of recovered elemental sulfur from crude oil and sour gas and byproduct sulfuric acid from nonferrous metal smelters is expected to increase substantially by 1990. Although environmental-related sulfur produced from coal-burning powerplants is a minor source of supply, it could become the major source of supply in the future. Additionally, processing facilities for the gasification and liquefication of coal and the retorting of oil shale are expected to generate substantial quantities of sulfur when brought into commercial operation.

9. WORLD MINE PRODUCTION AND RESERVE BASE

	Production		Reserve Base*
	1982	1983e	
United States	9,787	9,000	175,000
Canada	6,300	6,500	300,000
France	2,100	2,000	25,000
Germany, Federal Republic of	1,800	1,600	30,000
Italy	500	500	15,000
Japan	2,500	2,500	10,000
Mexico	1,900	1,700	100,000
Spain	1,000	1,000	30,000
Near East	1,200	1,500	400,000
Other Market Economy Countries	4,500	4,700	250,000
Centrally Planned Economies	19,000	19,000	1,000,000
World Total	50,600	50,000	2,300,000

10. WORLD RESOURCES

Resources of elemental sulfur in evaporite and volcanic deposits and sulfur associated with natural gas, petroleum, tar sands, and metal sulfides amount to about 5 billion tons. The sulfur in gypsum and anhydrite is almost limitless and some 600 billion tons are contained in coal, oil shale, and shale rich in organic matter, but low-cost methods have not been developed to recover sulfur from these sources. The domestic resource is about one-fifth of the world total.

11. SUBSTITUTES

There are no adequate substitutes for sulfur at present or anticipated price levels; some acids, in certain applications, may be substituted for sulfuric acid.

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* Pending establishment of criteria for the reserve base, classification of data is based on a judgmental appraisal of current knowledge and assumptions.

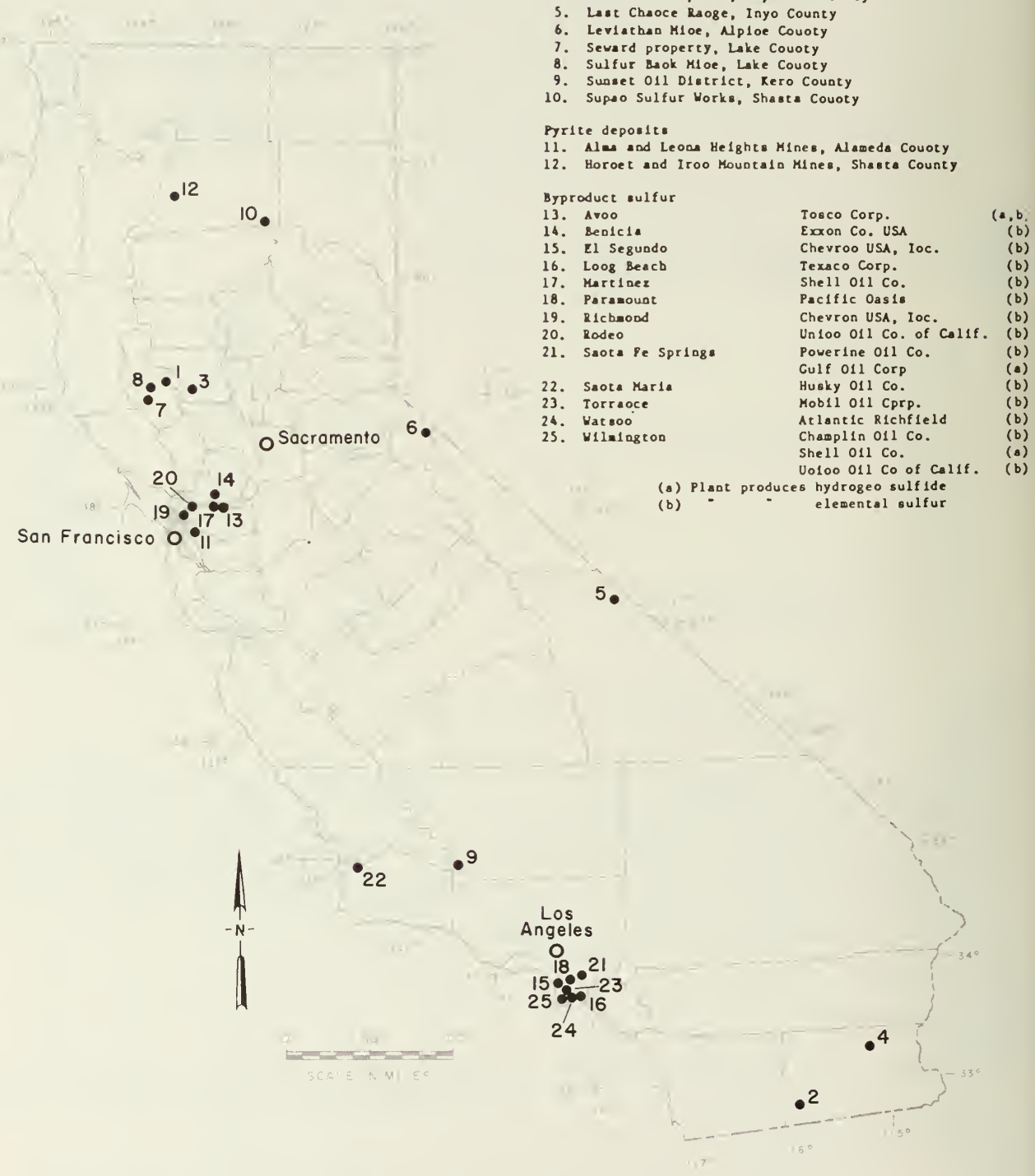
Native sulfur deposits
1. Chalk Mountain deposit, Lake County
2. Coyote Mountain deposit, Imperial County
3. Sulphur Creek area, Colusa County
4. Full Moon deposit, Imperial County
5. Last Chance Range, Inyo County
6. Leviathan Mine, Alpine County
7. Seward property, Lake County
8. Sulfur Bank Mine, Lake County
9. Sunset Oil District, Kern County
10. Supan Sulfur Works, Shasta County
Pyrite deposits
11. Alma and Leona Heights Mines, Alameda County
12. Horset and Iron Mountain Mines, Shasta County
Byproduct sulfur
13. Avon — Tosco Corp. (a,b)
14. Benicia — Exxon Co. USA (b)
15. El Segundo — Chevron USA, Inc. (b)
16. Long Beach — Texaco Corp. (b)
17. Martinez — Shell Oil Co. (b)
18. Paramount — Pacific Oasis (b)
19. Richmond — Chevron USA, Inc. (b)
20. Rodeo — Union Oil Co. of Calif. (b)
21. Santa Fe Springs — Powerine Oil Co. (b)
Gulf Oil Corp (a)
22. Santa Maria — Husky Oil Co. (b)
23. Torrance — Mobil Oil Corp. (b)
24. Watson — Atlantic Richfield (b)
25. Wilmington — Champlin Oil Co. (b)
Shell Oil Co. (a)
Union Oil Co of Calif. (b)
(a) Plant produces hydrogen sulfide
(b) " " elemental sulfur
Sacramento
San Francisco
Los Angeles
-N-
SCALE N MILES
34°
33°
117°
116°
115°

Figure 1. Locations of California sulfur resources.

PART II: CALIFORNIA

12. CALIFORNIA GEOLOGIC OCCURRENCES

Most of the native sulfur deposits in California are associated with volcanic rocks. Nearly all sulfur of volcanic origin occurs as disseminations, massive replacement bodies or veins. Disseminated sulfur is characteristic of deposits in which the ore grade is less than 50 percent, although such dissemination commonly form envelopes about richer massive replacement bodies. Large veins are usually found in the lower parts of deposits where the wall-rock is relatively unaltered. Sulfur formed by hot-spring action may be deposited in sediments at the bottom of warm lakes. Sulfur also as liquid flows from volcanic vents, as cement in near-surface alluvium, and as sublimates about sulfurous gas vents (Lydon, 1957).

13. CALIFORNIA LOCALITIES

A. Native Sulfur

Native sulfur production in California has been reported from Alpine, Colusa, Imperial, Inyo, Kern, Lake and Shasta Counties (Figure 1). The most productive localities were the Leviathan mine in Alpine County, and the Crater and Gulch areas on the west slope of the Last Chance Range in Inyo County.

Alpine County: The Leviathan mine, located about 10 miles east of Markleeville, has produced about 500,000 metric tons of sulfur which was mined and shipped to Yerington, Nevada by the Anaconda Company. The sulfur was used to manufacture sulfuric acid for leaching secondary copper ore at Anaconda's Weed Heights open pit mine. The sulfur ore body occurs as faulted, flat northwest-trending elliptical lens about 90 feet in maximum thickness and at least 2400 feet long (Clark, 1977). Sulfur has impregnated the lower part of a lake-deposited(?) tuff bed and part of the underlying andesite(?). The sulfur usually is coarsely crystalline and glossy. Sulfur in the andesite(?) or opalized tuff is less uniformly distributed. Mineralized rock exposed in the west wall of the main pit is broken and bright yellow sulfur fills fracture planes rather than pores as in the tuff. Mineralized tuff contained as much as 70 percent sulfur, but averaged about 30 percent. Mineralized andesite(?) has a wide variability in sulfur content, but averaged about 25 percent. Thick masses or veins of pure sulfur occured in both rocks but only rarely.

The mine closed in 1962 for several reasons: (1) ore away from the existing pit had a thicker overburden and mining there would increase mining costs; (2) the walls of the existing pit were caving and needed shaving to shallower slopes, and also increasing mining costs; and (3) Anaconda no longer was mining secondary copper ore and did not need acid leaching.

The mine was sold in 1963 and has not been worked since then. Sulfur resources still exist at the Leviathan mine but unless a nearby market can be developed for sulfur and the environmental problems which have plagued this mine cheaply solved, it is doubtful if any of the remaining sulfur will be recovered.

Colusa County: In 1891, the Elgin mine, near the head of Sulfur Creek, 4 miles northwest of Wilbur Springs, was operated and some 30-percent sulfur ore was retorted. Because of mercury contamination, the sulfur produced was black and could not be marketed. In 1918, another attempt was made to produce sulfur with two steam heated retorts. The operation terminated at the end of World War I without any production. Further attempts at sulfur production were made in 1929 by Pacific Sulphur and Industrial Minerals Company, when several sulfur tanks with a capacity of 4,500 pounds were built to hold coarse sulfur ore. The sulfur was melted with steam and removed from the ore, which was further processed for cinnabar. A total of 265 tons of ore was mined before the operation was abandoned in 1932.

At the Elgin mine, large quantities of crystalline sulfur, calcium and magnesium carbonates, and opaline silica are being deposited in shale and serpentine county rock by hot water and gases. The sulfur-bearing rock has been exposed in several adits and it was reported by Logan (1929) that samples taken over a width of 22 feet contained 52.6 percent sulfur. About one-fourth mile north of these workings at Little Sulphur Hill, the shale and serpentine have been altered intensely with the deposition of much crystalline sulfur, white carbonates and silica, and some cinnabar. Some open-cut work has been done here but no production has been recorded.

Imperial County: Two small occurrences of sulfur were worked in Imperial County between 1928 and 1932. One, the Coyote Mountain sulfur deposit, is located about 7 miles north of Coyote Wells on the east slope of Coyote Mountain. The sulfur occurs along a northeast-trending fault zone that is 8 to 10 feet wide and cuts granite, schist, and limestone. The sulfur is reported to be along fractures and seams in the rock for a distance of about 100 feet. The sulfur occurs with brown iron-stained gypsum and averages from 2 to 5 percent elemental sulfur. Development work consists of pits and an open cut in the hillside. Production, if any, is unknown.

The Full Moon sulfur deposit is on the southwestern slope of the Chocolate Range approximately 16 miles east of Niland. This deposit was located in 1928 and consists of sulfur deposited in fractures and seams in tufa. An open-cut, 12 feet deep and 40 feet in length, exposes sulfur scattered throughout the rock and filling seams. The deposit is surficial with a maximum depth of sulfur mineralization of about 10 to 15 feet. Development work consists of shallow shafts, short adits, and several open cuts. Production is unknown. The property is located on an aerial gunnary range.

Inyo County: In 1917, sulfur was discovered on the western slope of the Last Chance Range in Inyo County, about 5 miles west of the north end of Death Valley and about 48 miles east of Big Pine. The mineralized area is about 3 miles in length by 1 mile in width with a general north-south strike. Several north-trending faults cut Tertiary volcanic and sedimentary rocks in the area, and two principal zones of sulfur mineralization are parallel to and bounded by these faults (Lynton, 1938). These zones are each about 2,500 feet in length, and have irregular widths. Most of the sulfur occurs as steeply-dipping veins of various sizes, as shallow, flat-lying bodies, the disposition of which is probably controlled by fracturing in the rhyolite, and disseminated in bodies with indefinite boundaries (Lydon, 1957). Wallrock observed on the surface is a dense, white, silicified rhyolite, whereas drill holes and underground workings revealed wallrock of gypsum, conglomerate, and chert (Lynton, 1938). Scattered beds of essentially barren pumiceous tuff also are present. The Crater, Fraction, and Southwest Sulphyr claims lie astride both zones of mineralization, whereas the Gulch claims immediately to the south occupy a smaller mineralized area that appears separate from the other two areas. The sulfur occurrences are attributed to the oxidation of hydrogen sulfide gas, or its interaction with sulfur dioxide gas of volcanic origin. The hydrogen sulfide gas necessary for the reactions was derived from gypsum by the action of organic matter and carbonic acid water. Some sulfur was deposited by solfataric action (Vernon, 1951).

Principal development has been on the Crater group of claims near the north end of the mineralized area, the Fraction and Southwest Sulphyr group adjoining the crater group on the south, and the Gulch group near the southern end of the mineralized area. Although many claims were located in the area, little production of sulfur was made until 1929 when Pacific Sulphyr Company began mining operations on the Crater claims. This company mined through 1930. In 1931 and 1932, other operators worked the claims, and it is reported that 30,000 tons of 75-to-80 percent sulfur ore was shipped to Los Angeles by June 1932. In 1934, the Western Sulphyr Industries was reported to have shipped 4,500 tons of 96-percent ore; and in 1936 and 1937 Sulphur Diggers Inc. installed retorts and was reported to have shipped 5,000 tons of 96-percent ore and some refined sulfur. Since 1937, several other leasees have worked the Crater claims and have produced an unknown amount of sulfur. Production data from U.S. Bureau of Mines Yearbooks indicate that production was recorded for the Crater group of claims from 1958 until 1968. Mining was done by several different groups including the Inyo Soil Sulfur Company (1963-1967) and Magma-minerals Inc. (1968-1969). In 1969, North American resources did exploration on the Crater claims. No production is reported since 1969.

The Fraction and Southwest Sulphur group of claims were worked by the Italio Sulphur Industries Inc. in the late 1930s. Sulfur occurs in 7-to-85 percent sulfur. Ore recovered from a number of shafts, drifts, and open cuts was trucked to three sulfur ovens that produced sulfur in

175 pound cakes of 99.5 percent purity (Tucker and Sampson, 1938). Production from this operation is unknown, but 50 tons of refined sulfur were on hand when visited by Tucker and Sampson in 1938.

The Gulch group of claims is near the southern end of the mineralized zone. Sulfur occurs in pure, crystalline form intermixed with a kaolinized material in limestone, gypsum, and cherty shales. Three parallel seams of sulfur with a north-south strike and a 40° W dip, occur in the limestone. The sulfur seams vary in thickness from 10 to 20 feet. Development consists of short adits, shallow shafts and an open cut. Production from the Gulch group is unknown. Some sulfur was being mined from an open cut in 1955 for use as an agricultural mineral.

Production records from all claims in the Last Chance Range sulfur deposits are incomplete. Lydon (1957) estimated that the equivalent of more than 48,000 tons of 100-percent sulfur was produced from the area up to 1945. Since 1945, intermittent attempts at mining by different groups have yielded only a few thousand tons of sulfur used as a soil aid. When the area was examined in early 1984, the main pit on the Crater claims had been enlarged to about 200 feet (north-south) by 500 feet (east-west) and approximately 50 to 60 feet deep. Remains of the old plant remain on the site. Flat-lying beds of sulfur are exposed on the northwestern and northeastern corners of the pit wall as irregular veins and patches in altered rhyolite. The sulfur is overlain by a bed of white granulae gypsum at least 10 feet thick and, in some places, as much as 20 to 25 feet thick. The gypsum is overlain by a white tuff that is unaltered in some areas and appears to be altered in other areas along the north pit wall. Part of the altered material is natroalunite.

Sulfur resources certainly exist at this locality, but without drill hole data, no reliable estimates can be made. Lynton (1938) calculated possible sulfur reserves for the Crater area at about 2,500,000 tons of 40 percent sulfur ore. This possible reserve figure is based upon some drill hole data. No sulfur resource estimates have been made for the other areas. The principal deterrents to sustained production from the Last Chance Range have been high shipping costs and lack of water at the mining site.

Kern County: Small surficial deposits of sulfur were reported east of Maricopa in the Sunset oil field as early as 1893 (Watts, 1893). The sulfur ore varies in quality from nearly pure, grayish, amorphorous sulfur to rock permeated with sulfur crystals or as a cement in soil. Clay, gypsum, and bituminous matter are often associated with the sulfur. About 185 tons of sulfur ore are reported to have been shipped from this area in 1923-1924 (Branner, 1959).

Lake County: The Sulphur Bank mine, the Canary Hill mine at Chalk Mountain, and the Seward, Auschwitz, or S-Bar-S property have been of interest for their sulfur content at one time or another.

The Sulphyr Bank mine, on the eastern arm of Clear Lake was first worked for near-surface sulfur by the California Borax Company in 1865. The project was abandoned in 1868 because of a drop in sulfur price and difficulties in refining caused by increasing mercury content of the rock below the surface. The mine was reopened in 1873 and has been worked primarily for mercury. Production of sulfur for use as a soil additive was reported by the U.S. Bureau of Mines from 1958 through 1961. Early production is reported by Lydon (1957) to be about 941 short tons and by Everhart (1946) at 2 million pounds. Later (1958-1961) production was withheld.

In the mine area, contorted, slightly metamorphosed Franciscan shale and sandstone have been hydrothermally altered and unconformably overlain by lake beds and a recent augite andesite flow capped by 25 feet of white, powdery opaline silica formed by leaching. Gypsum and sulfur have been deposited in open spaces in this caprock. The rocks exposed in the open pits are almost everywhere affected by fault movements. Numerous hot springs and fumaroles occur in the fault zone. Sulfur is commonly precipitated in powdery masses at the orifices of the gas vents and hot springs.

The Chalk Mountain (Canary Hill) sulfur deposit is near Cache Creek about 4 miles north of State Highway 20. Traces of sulfur-bearing material, consisting mostly of sulfurous alum salts, occur in white, bleached andesite(?). Moderate amounts of hydrogen sulfide gas issue from the rock in a number of places. When examined in 1951, sulfur occurred principally as a cement in shallow debris and along joints in the wall-rock. Highest-grade material, exposed at that time, contained approximately 15 percent sulfur (Lydon, 1957). The property was worked before 1890 and intermittent attempts at development have occurred subsequently. Production, if any, is unknown.

The Seward, Auschwitz, or S-Bar-S deposit is located about a half mile south of the Kelseyville-Lower Lake highway. According to Lydon (1957), the principal deposit consists of sulfur disseminated in a cross-bedded, highly altered body of tuff which overlies an obsidian flow. The tuff apparently was deposited in a cup-shaped depression in the obsidian. Fragments of pumice and obsidian occur in the tuff, which strikes northeast and dips gently to the northwest. Sulfur is rather uniformly distributed throughout the tuff, but widely-spaced crevices are filled with relatively rich concentrations of sulfur. The deposit averages about 10 percent sulfur over an area less than 100 feet in its largest dimension. Development work consists of several short adits and an open cut. Production is reported by the U.S. Bureau of Mines from the S-Bar-S mine from 1959 through 1966. The operator, during at least part of this period, was the American Mineral Resources Development Company. Production data for this period of operation is incomplete except for 1964 and 1965 when 520 and 360 tons, respectively, were mined probably for use as a soil additive.

Shasta County: The Supan Sulphur Works, situated in Lassen Volcanic National Park, were discovered and located in 1865 and patented in the 1920s. From 1940 until acquired by the National Park System in 1951, the property was operated as a tourist attraction. Steam vents, mud pots and hot springs are the main features of interest here. Sulfur is deposited from gases as sublimated crusts, and from hot waters as crusts and impregnations. Production of sulfur, if any, was minor.

B. Sulfur from Pyrite

Sulfur has been recovered from pyrite (iron sulfide) in California since 1891 when the Alma Mine at Leona Heights in the Berkeley Hills, Alameda County, began operation. The pyrite ore is found in the Leona Rhyolite of Pliocene-Pleistocene age, which crops out as a narrow, discontinuous belt for about 22 miles along the west flank of the Berkeley Hills from Berkeley south to near Decoto. The known ore deposits extend over a distance of 2 or 3 miles and were developed by at least four mines apparently working the same ore body. These mines included the Alma worked by several operators including Stauffer Chemical Company, the Leona Mine operated by the Leona Chemical Company, and the Syndicate and Hotel Mines, operators unknown. The deposits consist of a series of irregular lenses composed principally of pyrite. The ore bodies are considered to be replacement bodies formed in a fracture zone that resulted from faulting (Lawson, 1914). The massive sulfide ore was derived from disseminated pyrite in the rhyolite. The pyrite was recovered by extensive underground tunnels and drifts. Excessive mining costs were responsible for the shutdown of the mines. Incomplete records indicate that about 350,000 tons of pyrite were produced from 1901 to 1934 when the mines closed. Production from 1891, when the Alma mine opened, to 1901 are unavailable. Pyrite from the mines at Leona Heights was used to make sulfuric acid.

Pyrite shipments were reported from a mine near Spenceville, Nevada County, by the Spence Mineral Company in 1897, the ore being shipped to the San Francisco Bay area for sulfuric acid manufacture.

Production of pyrite from Placer County was reported from the Dairy Farm Mining Company Mine near Sheridan in 1906 and 1915-1916, and from the Valley View Mine, 8 miles northeast of Loncoln in 1912.

The largest source of pyrite used for the production of sulfuric acid was the massive sulfide deposits of the mines collectively called the Iron Mountain Mine located about 17 miles by road northwest of Redding, Shasta County. The massive sulfide deposits of the Iron Mountain Mine occur in a porphyritic facies of the Balaklala Rhyolite. The principal ore bodies are large lenses of massive pyrite that contain copper and zinc and minor amounts of gold and silver. Production of pyrite from the various ore bodies (each with a different mine name) is about 3,600,000 tons. This ore was used in the production of sulfuric acid (Kinker and Albers, 1951). (Recoverable sulfur in pyrite averages between 40 and 50 percent.)

C. By-Product Sulfur

By-product sulfur production from oil refineries in California began in 1937 when Standard Oil Company of California reported recovery of hydrogen sulfide from its El Segundo refinery in Los Angeles County. The Shell Oil Company, with a refinery in Los Angeles County, first reported production of hydrogen sulfide in 1939. "Brimstone" or elemental sulfur production from hydrogen sulfide was first reported in 1949 by the Hancock Chemical Company, Los Angeles County. Production of oil-refinery by-product sulfur and sulfur dioxide has grown steadily since the end of 1948, and in 1982 was about 514,000 metric tons. Califoria ranked third in the nation for recovered sulfur produced in 1982. The 1982 production was from 16 oil refineries--four in Contra Costa County, ten in Los Angeles County, one in Santa Barbara County, and one in Solano County. These refineries produced either elemental sulfur or hydrogen sulfide from sour natural or refinery gases from which sulfur or sulfur compounds were eventually made. The Gribotol process or modification thereof is used in all refineries in California that remove hydrogen sulfide from refinery products. The Claus (Klaus) process, with modifications is used in all California producers of elemental sulfur from refinery gases.

The American Smelting and Refining Company smelter at Selby, Contra Costa County first reported output of sulfur dioxide as a by-product in smelting sulfide ore in 1937. It was used to manufacture sulfuric acid. Production of liquid sulfur dioxide as a by-product was first reported in 1953. The tonnage of by-product sulfur from flue gases was small and ceased in 1972 when the smelter closed down.

14. CALIFORNIA PRODUCTION

There is no production of sulfur from native sulfur deposits in California at the present time. Past production is incomplete and uncertain because of the lack of reliable production records, non-standard methods of reporting (no distinction between unconcentrated ore and refined sulfur, etc.), and unreported production. Lydon (1957) made estimates of the production of native sulfur in California from 1865 to 1954. This data is shown in Table 1.

Table 1. Production of native sulfur ore in California (1865-1954).

County	Short Tons (unspecified grade)	Short Tons (recalculated to 100 percent sulfur)
Alpine	450,968	127,053
Colusa	268	258
Inyo	60,729	50,246
Kern	385	172
Lake	941	894
TOTAL	513,291	178,623

Kinkel and Broderick (1966) have made an estimate of the pyrite and pyrrhotite production from which sulfur was recovered. This data is shown in Table 2.

Table 2. Production of pyrite and pyrrhotite for sulfur recovery.

Location	Long tons of sulfide ore
Iron Mountain Mine, Shasta County	4,500,000
Alma Mine, Alameda County	156,500
Leona Mine, Alameda	87,600
Spenceville Mine, Nevada County	150,000
Others (Dairy Farm Mine, Copper Queen Mine, Valley View Mine)	90,000
TOTAL	4,984,100

Evans (1966, p. 64) gives the sulfur production of the Leviathan Mine from 1952 through 1962 as 1,668,349 long tons of crude ore with a sulfur content of 465,616 long tons of 100 percent sulfur.

Native sulfur production as given by U.S. Bureau of Mines Minerals Yearbooks from 1955 through 1968 (exclusive of sulfur from the Leviathan Mine) is about 13,179 tons. This figure does not represent the complete production of native sulfur; the production records are incomplete.

By-product sulfur from oil refineries from 1953, the first year the data appears in the U.S. Bureau of Mines Yearbook, through 1982, with estimates for the years data was missing and excluding sulfur recovered from flue gases at the American Smelting and Refining Company smelter at Selby, is about 8,400,000 long tons.

Table 3. Total production of sulfur in California from all sources (1865-1982).

Source	Tonnage (long tons)
Native sulfur production 1865-1953), Table 1	162,547
Native sulfur from Leviathan mine (1954-1962)	427,729
Native sulfur from other mines (1952-1982)	13,179
TOTAL NATIVE SULFUR	603,455
By-product sulfur from pyrite (40% recovery from pyrite)	1,993,600
By-product sulfur from oil refineries (1953-1982)	8,400,000
TOTAL BY-PRODUCT SULFUR	10,343,600
TOTAL SULFUR PRODUCTION	10,997,055

15. UTILIZATION AND MARKETS

Many of the uses and markets for sulfur discussed in Section 1 of this report also apply to California. In California, the consumption pattern of sulfur and sulfuric acid is complex because of the diversity of agricultural and industrial enterprise. Sulfur and sulfur equivalent export-import records for the state are not kept by any central agency. Such information is held largely by the individual companies acutally involved in the sale, purchase, and transportation of pertinent goods (Lydon, 1957).

Some information about the use of sulfur in agriculture in California is available from the California Department of Food and Agriculture. This department publishes a quarterly summary of state and county sales of commercial fertilizer and agricultural minerals. According to Rollins (1951), sulfur is an important element in California agriculture. Sulfur as a dust or in sprays such as lime-sulfur solutions or as wettable sulfurs, is used to control pests that attack fruit trees as well as truck and field crops. In 1982 and 1983, about 2,000 tons of lime-sulfur were consumed each year. Large amounts of elemental sulfur and sulfur compounds are applied to soils in the state. When elemental sulfur is added to soil, it is converted to sulfuric acid by bacterial action. For this reason, elemental sulfur is used to treat alkaline soils which contain detrimental excess of sodium carbonate. The ultimate action of the sulfur converts the sodium carbonate into sodium sulfate, which is more readily removed by leaching. Large amounts of sulfur are also used to supply the element for plant nutrition. About 50 years ago, sulfuric acid was tried experimentally for the treatment of alkaline soils and, until 1947, no appreciable amount was used for this purpose. The acid is applied either by spraying it directly onto the soil or by metering it into the irrigation water. Large dosages are not applied to growing crops because it may injure them, but they are added to the soil at least 2 months before planting (Rollins, 1951). Tonnage of elemental sulfur and sulfuric acid used in California agriculture during 1982 and 1983 is shown in Table 4.

Table 4. Tonnage of elemental and sulfuric acid used in California agriculture.

Year	Sulfur (tons)	Sulfuric acid (tons)	Total (tons)
1982	20,088	19,594	39,682
1983	18,367	28,567	46,934

16. MINING METHODS AND BENEFICIATION

Most of the mining of native sulfur in California was done by open pit methods or by shallow shafts and short drifts or a combination of underground and surface methods. The Leviathan Mine was mined by open pit methods using 35-foot benches during the stripping of the up to 350 feet of overburden. During the mining of the sulfur ore body 15-foot benches were used. The ore was blasted using a special mixture of ammonium nitrate, molasses, and water because of the highly inflammable nature of the sulfur. Blasted ore was hauled by trucks to a crushing plant at the mine site, crushed by a 5-inch jaw crusher, and stored in ore bins before being hauled to the sulfuric acid plant in Nevada. No other beneficiation was done on site at the Leviathan Mine.

The sulfur deposits in Last Chance Range were first worked by underground methods (shafts and drifts) but, because of the hazardous nature of the country rock, were later mined by open pit methods (cuts, pits, and trenches). Beneficiation methods are not available. However, at least one attempt was made to produce high-grade sulfur by the use of steam retorts. Most of the recent production here appears to have been agricultural sulfur (40-50% sulfur) where the sulfur grade was maintained by selective mining of higher grade parts of the deposit. This appears to have been the method used at several of the smaller deposits also.

17. CALIFORNIA EVENTS, TRENDS, AND ISSUES

With the closing of the Leviathan Mine in Alpine County in 1963, all reported native sulfur mined in California has been used as a soil additive. Sulfur for this purpose has been produced since 1963 from two localities in Lake County and one from Inyo County. Both operations in Lake County (Sulfur Bank and S-Bar-S) were small open pit operations. The last operation at the Crater Claims (Last Chance Range) in Inyo County was also on open pit operation.

Environmental problems at both Lake County operations were probably not considered during the last period of operation between 1958 and 1966. With the enactment of the Surface Mining and Reclamation Act of 1975 in California, reclamation and environmental consideration would have to be considered in planning a mining operation. On the other hand, reclamation and environmental problems at the sulfur deposits in the Last Chance Range are probably negligible because of the lack of water, vegetation, and

urbanization. Further mining at the Leviathan Mine would be costly and possibly unprofitable because of problems created by the heavy snowfall and subsequent run-off, and problems created by previous mining.

Sulfur ore can be produced profitably in California only when it can meet the competition of the delivered price of Frasch sulfur from the Gulf states. Profitable small operations of sulfur ore for soil aid may be possible by selective mining and keeping the cost of mining below the Frasch price plus the freight to the point of consumption.

18. CALIFORNIA REFERENCES

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